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Art. XIII.—*The Geological Structure of the Lower Ordovician Rocks of Eastern Talbot, Victoria.*

By WM. J. HARRIS, B.A. and D. E. THOMAS, B.Sc.

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I. Introduction.

The present paper is an account of the palaeontological succession in the region south and west of Castlemaine as deduced primarily from the study of its Lower Ordovician graptolites. Graptolites of younger age are not known from this district. The area is, roughly, a rectangle containing over 1,000 square miles, and including the eastern half of the County of Talbot and a smaller area in the south-west of Dalhousie. Its northern boundary is the Mount Tarrengower–Alexander granitic massif, its southern the Great Divide, its western the volcanic rocks covering the Moolort–Loddon Deep Leads system, and its eastern, roughly, the Kyneton–Redesdale railway line. The north-eastern sector of about 100 square miles was dealt with in some detail by one of us in 1916(9), but circumstances prevented the continuation of the work until three or four years ago, when it was resumed. Dealing with a larger area, and one more difficult to study in detail on account of distance from

centres of population and paucity of artificial excavations, the treatment adopted in the present paper is more general than that in the earlier paper. This more general treatment was also made desirable by our plan to give a comprehensive account of the structure of the district. Towards the latter part, suggestions will be found for detailed work in critical localities.

II. Previous Workers.

For so extensive an area it is impracticable to give a detailed list of all maps and papers which may with profit be consulted. The following summary, though incomplete, will provide a basis for those who wish to study the area in detail.

1. The greater part of the area is covered by Quarter-sheets(22) of the Geological Survey of Victoria, published between 1860 and 1870. The amount of detail shown on these maps varies, some, such as 15 N.E., being particularly fine examples of the geological surveyor's work, others leaving extensive areas unmapped or merely outlined.

Other maps include geological survey plans of parishes(23)—a particularly good example being the plan of Campbelltown—and maps accompanying reports, &c., on gold-fields such as Castlemaine, Maldon, Daylesford, and Lauriston. None of these maps shows more than a few of the hundreds of localities from which graptolites have been since recorded. For a general view of the geology of the whole district, the best maps are probably those included in "The Deep Leads of Victoria"(4). This memoir also gives a bibliography, which includes articles on most parts of the district now dealt with.

2. A detailed bibliography up to 1903 is given by J. W. Gregory in the "Records of the Geological Survey"(5). Later incidental contributions are scattered through various publications of the Victorian Mines Department.

3. Dr. T. S. Hall in his "Geology of Castlemaine"(6) gave a general account of the geology of the district around Castlemaine, and zoned the Castlemaine graptolite series. Hall's paper deals chiefly with the area east of a north-south line through Castlemaine.

4. The present Secretary for Mines in Victoria (W. Baragwanath(1)) in "The Castlemaine Gold-field" included a detailed map showing axial lines, and an east-west section showing the area as the eastern limb of a synclinorium.

5. Harris(9), in 1916, verified Hall's zoning and carried the study of structure west to the line of Muckleford Creek, showing that in the area between Castlemaine and Guildford there are beds characterized by *Oncograptus* and *Cardiograptus*, and that

these beds are stratigraphically between the Upper Castlemainian and Darriwilian of Hall. This extended Darriwilian was provisionally zoned.

6. For the Maldon area, the chief authorities are Moon(18) and Bradford(2).

7. Lidgey(17) published a description and map of the Malmsbury and Lauriston gold-field.

8. The Daylesford district has been discussed from one aspect or another by W. Baragwanath and H. S. Whitelaw(20, 21), and by T. S. Hart(11), while extensive collections of graptolites were made from that district by T. S. Hart and W. H. Ferguson. Identifications from these collections were made by Dr. Hall. Ferguson, on an unpublished plan, also delimited the graptolite zones of the district on the basis of the graptolites he collected.

9. For the southern part of the area we have used unpublished records of the work of the late H. Foster, formerly of the Geological Survey. Foster's painstaking detailed work has enabled us to plot the structure of an extensive area hitherto little known, and to connect it with the better known area to the north.

10. For the western portion of the district between Yandoit and Campbelltown, T. Smith has made available to us the results of many years of careful field work. This enthusiastic worker's records, from a district where even such an experienced field geologist as Norman Taylor failed to find fossils, enabled us to confirm the conclusions which we had drawn from our own rather scanty collections along the western boundaries of our district. Mr. Smith not only placed his extensive and valuable graptolite collections at our disposal, but acted as our guide in visits to critical localities in the Yandoit district.

For the rest we have relied on our own field work, particularly in the Maldon–Newstead area, south of Guildford, and around Woodend, Kyneton, Lauriston, and Taradale, not to mention large areas which have been unsuccessfully prospected for fossils. Even in the areas from which we have recorded the results of other workers, we ourselves have in most cases verified the main points in the field.

In conclusion, we gratefully acknowledge the encouragement and practical assistance of the Secretary for Mines (Mr. W. Baragwanath), whose detailed knowledge of the structure of the gold-fields of Victoria is probably unique. Without Mr. Baragwanath's interest, the preparation of this paper would have been impracticable. As on other occasions, the draughting staff of the Mines Department have come to our assistance in the preparation of maps and sections for publication.

III. Physiography (*vide* Map 1).

The area under discussion lies north of the Main Divide, and with the exception of the eastern portion is entirely within the drainage basin of the Loddon River. The eastern section drains to the Coliban and the Campaspe. The main physiographic control seems to be the granitic massif which extends on the north from Maldon to Metcalfe and Taradale. The Cobaw granitic massif further south-east has also influenced the Campaspe drainage. The Loddon collects its water not only from the northern slopes of the Main Divide, but from practically all the inner or southern arc of the Tarrengower–Alexander massif (cf. Geological Map of Victoria), while the Coliban and the Campaspe drain the south-eastern portion of this massif, and flow northwards between it and the Cobaw Ranges.

The Tertiary lava flows also have a profound bearing on the present drainage system, the main watercourses being either laterals with relation to the flows or else occupying central depressions on them, as, for example, long portions of the Campaspe. It will be shown later that the lavas for the most part followed drainage channels already established in late Tertiary times; these in turn are intimately related to the present streams.

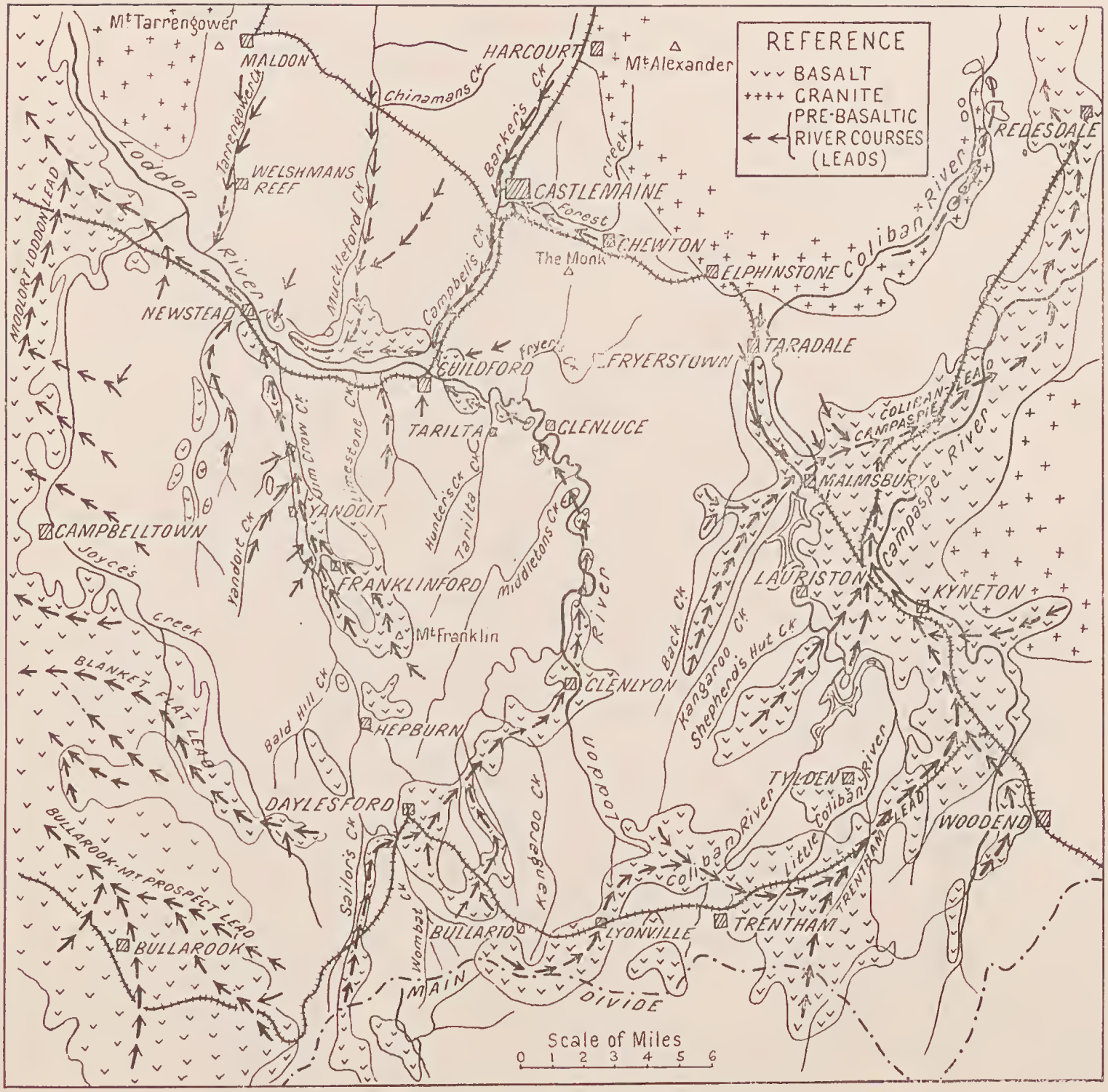
The third factor is the relative hardness of certain Lower Ordovician strata. The general strike of these rocks is almost north and south (usually a little west of north), and a great number of streams, particularly tributaries, flow in this general direction for a greater or lesser distance.

These factors, together with the position of the Main Divide in the south, make the drainage scheme intelligible.

The Loddon flows in a northerly direction from its source in the south centre of the area, and then turns westward, to leave the map near Newstead. It is fed by a number of tributaries which for the most part follow, as we have said, either north or south courses. None of these streams has a large catchment area, and as the whole district is one of only moderate rainfall, the Loddon receives little water from any tributaries in the mapped area, except in winter and after rains. For the greater part of the year, practically all the smaller creeks are either dry or reduced to a mere trickle.

The Coliban River flows through the eastern section, and its chief tributaries, which also have a northerly course—the Kangaroo (near Taradale), Back, and Shepherd's Hut Creeks—are good examples of lateral streams. Near Taradale, the Coliban enters the Mount Alexander granite massif, and then for some distance flows just inside the border of the granite.[1] The border of the igneous masses has proved weaker than either

[1] Here, as elsewhere, the term granite is used in a popular sense. The rock is for the most part a granodiorite rather than a true granite.



Map 1.—Pre-basaltic and present-day Drainage Systems.

the main mass of the igneous rock or the contact selvages of the sedimentary rocks, so that usually a valley runs parallel to the edge of the granite and just inside it. As a result of this, the Elphinstone–Faraday–Harcourt road keeps just within the granite of the Mount Alexander massif. The hardened aureole of sedimentary rock, on the contrary, stands up as a more or less continuous ridge, though breached in places by streams. Mount Tarrengower is an example of such a hardened mass, while similar conditions in the east cause the Melbourne–Bendigo railway to enter the Loddon Valley through a tunnel near Elphinstone, and to leave it by a similar tunnel near Ravenswood. Barker's Creek has breached the hardened belt near Harcourt, or a third tunnel would have been required.

In keeping with the north-south direction of the main valleys the chief ridges are also meridional, but minor streams often run either east or west, and in the field it is difficult to follow any definite north-south ridge for any considerable distance. It is only on a map, or from some specially favorable view-point, that the north-south trend of the main ridges can be seen.

IV. Evolution of the Drainage System.

The pre-basaltic drainage system can be followed with some degree of precision, as the old auriferous river gravels have been mined in most parts of the district. Data regarding these old "leads" may be found in Hunter's "Deep Leads of Victoria"(14), and in order to make the present drainage system intelligible, the pre-basaltic drainage lines must be reconstructed.

In "Deep Leads" times two main streams which have been called the Loddon and the Campaspe Deep Leads systems(14) drained the area. The Loddon Deep Leads system occupied approximately the present Loddon drainage basin, but the main stream flowed under the present basalt plateau, west of the mapped area, and therefore west of the present Loddon. The lava flows here are very extensive, and are of the type called by Keble(16) "unconfined" lava flows, although they occupy the wide and flat valleys which existed when they were poured out. The details of the drainage were altered considerably, but the general northerly trend was maintained. The present streams are much smaller than those represented by the Loddon–Moolort Deep Leads system. Joyce's Creek developed as a lateral along the eastern flanks of the Moolort lava flow, and collected the drainage which formerly flowed westward to the earlier main channel. The present main stream, the Loddon—in earlier times only a large tributary—maintained the general direction of its pre-basaltic representative, the valley of which had been followed by a long but comparatively narrow flow of lava. Flowing down the same valley, the stream took the line of least resistance, and meandered from one side of the basalt to the other, leaving

"islands" of basalt standing alternately above either bank as flat-topped plateaux. The most extensive of these plateaux is that north of Guildford. Often the lava flow was not sufficient to cover all the old gravels, which in these cases still survive as hills without a volcanic capping.

The Coliban–Campaspe system is most interesting. In "Deep Leads" times the Campaspe drained almost the whole of the eastern area. The Leads systems show that the main stream of the Campaspe rose south of Bullarto and flowed north-easterly towards Kyneton, where it was joined by a west-flowing stream from between the Cobaw and Macedon uplands. It then flowed north-west and was joined by tributaries from rising ground near the present Upper Coliban Reservoir, and then by a stream represented by the Malmsbury–Taradale Deep Lead. Boring records show conclusively that near Malmsbury this stream received the Taradale drainage from the north (see also Note 3, Q.S. 9 N.W.). The Coliban therefore could not have drained much of the area, and its course was confined to the eastern edge of the Mount Alexander granitic mass. Here lava residuals, perched on hills alongside the present stream, show the course of the pre-basaltic Coliban.

The Divide between the Coliban–Campaspe and the Loddon was in practically the same position as at present, but, as indicated, the distribution of the drainage between the Coliban and the Campaspe differed considerably. The basalt flows in this area are complicated and have been derived from many sources. It is evident, however, that lava filled the old main valley and effectively dammed part of the outlet between the Cobaw Ranges and Mount Alexander. Lateral streams developed along the western edges of the flows, but meeting other south-west to north-east flows, had to cut across their necks. The Campaspe was altogether blocked south of Carlsruhe, and from Kyneton to East Metealfe it had to flow over the surface of the basalt. After this it secured an easier path, first as a western lateral, and then, having crossed the lava near Barfold, as an eastern lateral.

The drainage of the original head streams near Trentham was disorganized. Many laterals developed, some of them crossed the narrower parts of the lava flows, as at the Trentham falls, but all were seemingly diverted northwards when they approached the main flow. They then either broke into the Coliban system or were captured by the Coliban, working back through the soft granite selvage. The result is that the initially shorter stream, the Coliban, has enlarged itself by capturing most of the pre-basaltic western tributaries of the original Campaspe.

The basalt flows have introduced new features into the topography-plains, flat-topped hills and plateaux, ridges, deep gorges, asymmetrical valleys, ungraded rivercourses with notable waterfalls, and even river capture on a large scale.

V. General Geology.

(*a*) *Rocks of the Area.*

The basal rocks of the whole district are the Lower Ordovician sandstones and shales, but younger rocks are well represented. The following list will give some idea of the general geology:—

(i) *Post-tertiary.*—Surface soil, present river gravels, and alluvial material. The nature of this indicates its wide-spread occurrence.

(ii) *Tertiary.*—The rocks of this age are either river deposits or of volcanic origin. The volcanic rocks are not all of the same type, but are usually grouped as "Newer Basalts." Though now found often as hill cappings, they seem for the most part to have originally been lava flows down the old valleys. There are also some volcanic necks, occasionally with small associated flows. It is not clear whether some of these at least may not belong to the so-called "Older Basalts." Mount Consultation (locally called Bald Hill), near Castlemaine, is an example of this class. Lastly, there are the "lava dykes" through the sediments, referred to as limburgite (1, p. 34), but including other types of rock.

Gravels, often auriferous, occur both as surface cappings and as beds underlying the basalt. These gravels have been divided by the Geological Survey into two classes—Newer and Older Pliocene.

The lava flows were probably responsible for the formation of small lakes, since small deposits of limestone are found in many places, sometimes with freshwater shells, as along Limestone Creek and near the mouth of Muckleford Creek.

(iii) *Permocarboniferous.*—A small patch of glacial tillite occurs in the Parish of Campbelltown, in the west of the area, and traces of similar rocks are found elsewhere in the same parish and along the Coliban River north of Tylden. Sandstones, referred to the same general age, have been quarried near Kyneton for use as building stone.

(iv) *Devonian.*—The granodiorites and granites of the Mount Alexander massif and the Cobaw Ranges are instrusive into the Lower Ordovician, and by analogy with similar rocks elsewhere in Victoria, are dated as at the close of the Devonian. A small intrusive mass south of Tarilta is marked on Q.S. 15 S.W. as syenite, but is more probably lamprophyre.

(v) *Ordovician.*—The "bed-rock" of the district is Lower Ordovician in age. Sandstones, shales, and claystones are found, limestone being absent. In some places, as near Castlemaine, the shales have been altered to slates, which have been quarried as flagstones. Graptolites are to be found in all types of the finer sediments, but their extraction is rendered difficult either by the

entire absence of cleavage, as in many of the claystones or mudstones, or by the development of cleavage at varying angles to the lamination. Lithology is no guide to age, as Lancefieldian graptolites may be obtained from rocks which in appearance might well be mistaken for either Bendigonian or Castlemainian. Two generalizations may be made with some reserve—beds with thin black bands through lighter-coloured shales are likely to be Lancefieldian, while thick beds of rather thin-bedded bluish-purple shales are likely to be Darriwilian. Still, there are so many exceptions, particularly to the latter statement, that only the discovery of fossils is decisive.

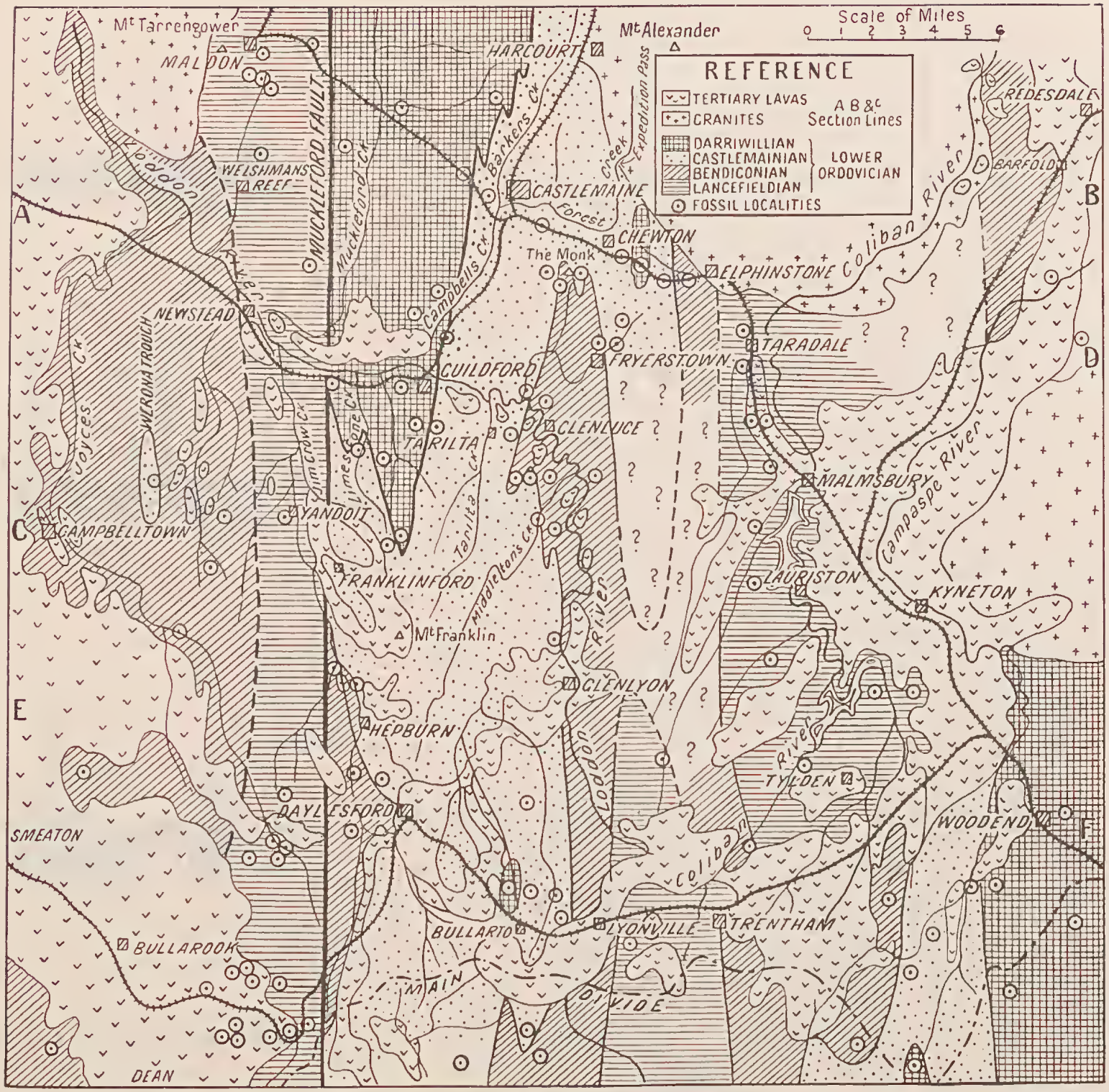
(*b*) *General Structure* (vide *Map* 2 and *Sections*).

For convenience, the general structure of the district will be considered before dealing with the distribution of the various graptolite zones on which our interpretation of this structure is mainly based.

The main structural lines trend a little to the west of north, as plainly indicated by the strikes noted on the various Quarter-sheets. One of the main axial lines is the Maldon, Dean anticlinoria in the west of the mapped area. On the western flank of this, Bendigonian beds appear to follow in normal succession, with at least one small area of Castlemainian in the Werona synclinorium, but the eastern limb is truncated through probably the whole length of the map by what must be regarded as one of the major geological features of the district—the Muckleford Fault.

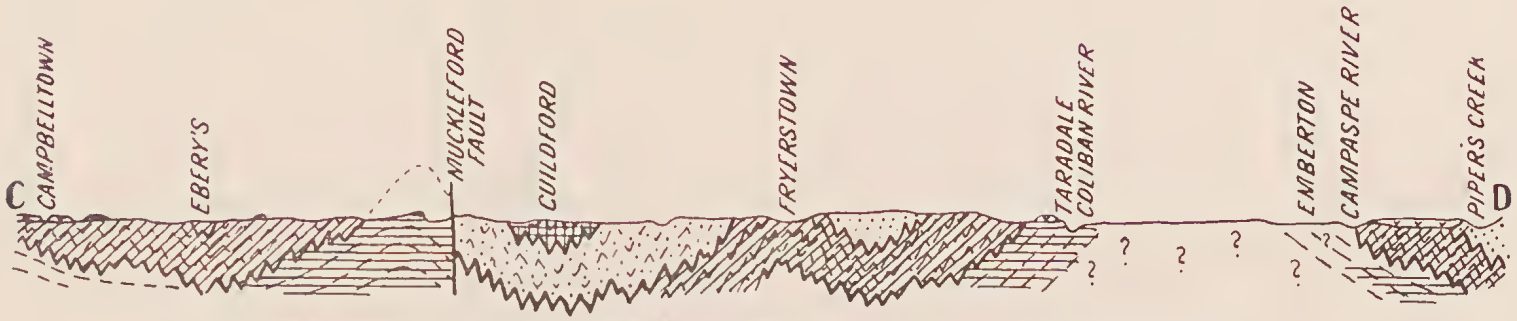
These anticlinoria are succeeded to the east by the Muckleford–Bullarto synclinorium. Still further east is the Chewton–Lyonville anticlinorium, which becomes more pronounced to the south. A small synclinorium intervenes between it and the next major anticlinorium—the Taradale–Lauriston. The continuation of these anticlinoria and synclinoria to the south must be left for separate treatment. A wide stretch of Darriwilian rocks along the Gisborne Creek and as far north as Woodend forms a break between the area mapped and the Bendigonian beds outcropping in the Pyrete Ranges(10). It may confidently be predicted that a succession of anticlinoria and synclinoria similar to that dealt with will be found south of the Main Divide, but detailed mapping will be required before it is known how far faulting has modified the succession.

West of the area mapped in this paper, no rocks high in the Castlemainian or of Darriwilian age are known to occur, but to the east there is in the south a wide expanse of Darriwilian beds, giving place still further south to the Upper Ordovician of the Riddell synclinorium(19). North of Mount Macedon, Darriwilian beds also occur in a broad east-west belt, but are cut off in the north by the Cobaw massif, north of which the most widely distributed series are the Castlemainian and Bendigonian.

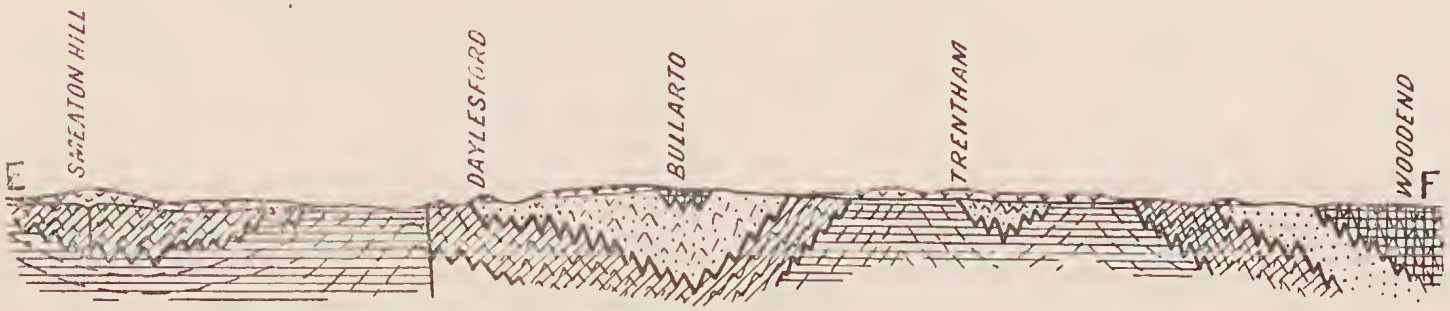


Map 2.—Structural Sketch Map of East Talbot Area.

DIAGRAMMATIC SECTION FROM JOYCES CREEK TO BARFOLD (A-B)



DIAGRAMMATIC SECTION FROM CAMPBELLTOWN TO PIPERS CREEK (C-D)



DIAGRAMMATIC SECTION FROM SMEATON HILL TO WOODEND (E-F)

BASALT GRANITE DARRIWIL SERIES CASTLEMAINE SERIES BENDICO BEDS LANCEFIELD BEDS

Scale of Miles

0 1 2 3 4 5 6 7 8

Diagrammatic Sections (see letters on Map 2) to illustrate General Structure of Area.

(*c*) *Structural Detail.*

The positions of the anticlinoria mentioned above have been fixed by the record from them of graptolites of the older series, particularly the Lancefieldian, the plotting of dips being unreliable, since in the field close folding makes it impossible to distinguish major from minor lines of folding. Some of the more obvious anticlines, as for example in the neighbourhood of the Town of Castlemaine, are almost immediately "cancelled out" by less prominent synclines. From the plotting of the graptolite zones it is evident that pitch is a very important factor when considering such a large area, and observed angles of pitch, though not numerous, show that the effects attributed to it cannot be considered exaggerated. It must be realized that over a wide expanse of country individual folds are usually elongated troughs or domes, and when followed along the line of strike die out, to be succeeded by similar features along parallel lines. Hall (6, pp. 64-65) has referred to this in his account of the Castlemaine district. It follows, therefore, that when an anticline is traced for a considerable distance along the line of strike, younger beds will occur along the nose of the fold. This is usually so gradual that it is rarely observable except when observations from an extensive area are plotted. It is very noticeable on the map (Fig. 2) for the more complicated structures, as, for example, in the Chewton–Lyonville anticlinorium, where Lancefieldian beds near Lyonville are followed by Bendigonian from Glenlyon to the Monk Hill (Castlemaine), then by lower Castlemainian at Chewton and higher Castlemainian further north.

The structures termed anticlinoria are really complicated domes. The latter term brings out the fundamental structure of Victorian Ordovician rocks—viz., isolated areas of older beds surrounded by younger ones. Frequently, as one dome loses its importance and dies out, two others arise, one on either side of the first, so that the anticlinal structure of that belt gradually becomes a synclinal one. The term dome has not been used, as it has a restricted and particular meaning in Victorian mining geology.

The folding of the area is very close, and therefore the outcrops of the various zones are much more complicated than a small-scale map will indicate. Such a map must necessarily be generalized. For this reason, the structural features have been considered in the wider terms of anticlinoria and synclinoria, or domes and troughs, leaving more detailed treatment of boundaries for the future. Faulting is common, as can be seen in any large outcrop and in plans of most of the mines, but it is only when a fault is of considerable magnitude that it can be traced in the field or indicated on the map. The absence of fault lines from the plans is therefore no indication that they do not exist.

VI. Distribution of Graptolite Series and their Relation to Axial Lines.

(*a*) *Maldon, Dean Anticlinoria, and Werona Synclinorium.*

This area, west of the Muckleford Fault, shows Lancefieldian beds at Maldon, near Fentiman's Reef (east of Maldon), along the Tarrengower Creek, east of Newstead, west of Yandoit and Franklinford, and in the Parishes of Bullarook and Dean. These are the beds below those characterized by the appearance in force of *Tetragraptus fruticosus*, and are marked by the presence of *Dictyonema, Bryograptus, Clonograptus,* and *Tetragrapti* such as *T. decipiens* T.S.H. and *T. approximatus* Nich. Fossiliferous outcrops are not as common as one would desire in this belt, but as Lancefieldian graptolites are often confined to very thin soft black bands interbedded with silky shales and massive sandstones, and are only observable under favorable conditions, it is rather remarkable that so many outcrops have been located in a region where artificial excavations are not common. The western beds of this anticlinorium appear to show the normal rise to Bendigonian at Dean, Smeaton, Campbelltown, and west of Newstead. In the Parish of Campbelltown, lower Castlemainian (*Didymograptus* cf. *bifidus*) beds are represented —one of the most westerly occurrences in Victoria as far as we are aware—indicating a synclinorium in the extreme west of the mapped area—the Werona synclinorium.

The eastern limb presents a different picture. Only to the south do Bendigonian beds appear, and even here they are apparently of less than normal extent, partly due to faulting, as will be described presently, and partly due to pitch—southerly, south-west of Daylesford, and northerly, near Hepburn. North of Hepburn, Castlemainian beds seem to make contact with the Lancefieldian of Yandoit, while still further north there is a great development of Darriwilian rocks in the Guildford–Bullarto synclinorium and a most pronounced break in the normal succession. The whole of the evidence points to a fault line just west of, and parallel to, Muckleford Creek, and continued southward. The Quarter-sheets, as far as they include this portion of the district, show two features of interest:—(1) The graptolite localities recorded by the old survey are much less frequent west of this line than further east—in fact, only two or three localities are marked to the west; and (2) the quartz reefs so carefully marked on these old plans are much more numerous in the western belt, and show up as a band of closely packed parallel lines with a general trend a little to the west of north, in contrast with the more open arrangement to the east. In the field, the predominance of sandstones and the almost complete absence of belts of black slate are notable. All these features give reasonable grounds for suspecting that the valley of the Muckleford Creek roughly marks an important structural break

in the country, and our field work confirms this. In amount of throw, and in the faulting of Darriwilian against Lancefieldian, as well as in the normal rise to Bendigonian on the east, it compares with the Whitelaw fault (Harris, MS.) in the Bendigo East district.

(*b*) *Muckleford–Bullarto Synclinorium.*

This synclinorium is marked by the extent of Darriwilian rocks in the north. Further south, high Castlemainian beds appear, indicating a northerly pitch in this part. There is apparently a reversal of pitch still further south, indicated by a patch of Darriwilian near Bullarto. In the extreme south the succession passes from Darriwilian beds through Castlemainian to Bendigonian, so that the pitch seems to be again northerly, and the syncline dies out.

(*c*) *Chewton–Lyonville Anticlinorium.*

The general pitch of this anticlinorium is to the north, with some relatively unimportant reversals. It is represented by a wide but northerly-narrowing belt of lower Castlemainian between Chewton and Wesley Hill (east of Castlemaine), Bendigonian from the Monk Hill nearly to Lyonville, and Lancefieldian in the south occupying a wide belt between Lyonville and Trentham.

(*d*) *Expedition Pass Synclinorium.*

This is seemingly a smaller feature than the others dealt with, and brings upper Castlemainian up at Expedition Pass, lower Darriwilian half-way between Chewton and the Elphinstone railway tunnel, and upper Castlemainian further south, and is then represented on our map by a belt of Bendigonian, the existence of which is only inferred from records to the east and west. This southern strip covers rough country crossed by few tracks, and almost lacking in good rock exposures except in the larger creeks. What exposures there are show for the most part sandstones and sandy shales, while nothing but sandstone shows on the slopes even where the surface is not obscured by thick scrub. Detailed work, which will take much more time than we were able to allot to this area, will be necessary before any possible graptolite outcrops can be located. Here we are compelled to fall back on inference and on the very doubtful evidence of lithological resemblance. This, for what it is worth, would seem to negative the suggestion that the belt is Darriwilian, but there is no positive evidence as to which, or how many, of the lower series may be represented.

(*e*) *Taradale–Lauriston Anticlinorium.*

This anticlinorium, like its western counterpart, is one of the major features of the district, and the evidence on which it is plotted is conclusive, for the records, though comparatively few, are well spaced. The most northerly record is from near the

Taradale Railway Station. South of this, the surface is almost entirely composed of basalt, but nearly every mine dump examined yielded Lancefieldian graptolites. This welcome result is all the more acceptable as there were rarely more than a few weathered fragments of black shale available, and these so badly cleaved that often a consultation was necessary to determine in which direction the precious fragments should be broken. Still further south, a good collection was made from the Kangaroo Reef, at Lauriston (near the old survey locality Ba 77, Q.S. 9 S.W.). Lancefieldian graptolites have been collected from Shepherd's Hut Creek and the Coliban River by H. Foster, and they also occur near the Kyneton–Tylden road.

In the extreme south, younger beds occur along the line of strike. This feature can be explained by a marked southerly pitch. This we think is the probable explanation, but in the absence of direct evidence other explanations, such as faulting, are possible. It is here also that we again meet the difficulty referred to under (*d*) above. The area between Glenlyon and Drummond is the southern continuation of the Taradale–Glenluce belt. It represents rough unpromising country, but is practically unexplored as far as graptolites are concerned. Our own trips through it have been fruitless, but there is no reason why a greater expenditure of time may not yield important results. In the absence of records we have presumed that a narrow belt of Bendigonian divides the Taradale–Lauriston anticlinorium from the Chewton–Lyonville line.

(*f*) *The Eastern Belt.*

This area will be treated more or less sketchily since it lies outside the area on which we have mainly concentrated our attention. Moreover, the development of granitic and volcanic rocks is so extensive that the axial lines can be understood only when studied as part of a larger unit outside the present mapped area.

To the north-east, the Taradale Lancefieldian seems to be succeeded normally by Bendigonian, which is shown below Mitchell's Falls (near Barfold), and by Castlemainian further east. In the south-east, Castlemainian beds south-west of Woodend and an extensive area of Darriwilian east of them extend far to the south, towards the Woodend–Newham–Rochford–Gisborne area, which fringes the Upper Ordovician of the Riddell synclinorium.

South of the mapped area the succession is broken along a north and south line by the Djerriwarrh Fault. The extensive area of the Darriwilian south-west of Woodend and in the valley of the Gisborne Creek west of Macedon, taken together with the distribution of lower zones north and south of this section, as for example in the Pyrete Ranges, would seem to imply the existence of numerous smaller faults, which, however, cannot be demonstrated. The extent to which faulting must be invoked

to reconcile discrepanies can be determined only by detailed field work. The following extract from Whitelaw's account (21, p. 13) of the structure of the Daylesford gold-field will indicate the important part that faulting may be assumed to play:—"Subsequently to the folding which they have undergone, the beds have been cut into innumerable slices by west-dipping thrust-faults, which, on the eastern side of the main anticlines, form the principal reef-channels of the field. There has been considerable movement upwards on the western side of most of these faults, which fact, no doubt, in a measure accounts for the appearance at the surface of the closely-folded intensely-fractured Bendigonian beds of the western area. . . The most graphic description would not half so well convey (as the plans and sections) to the interested person the manner in which the folds—the arches and troughs—have formed, rolled out, and re-formed; how and where they converge, diverge, and throw out laterals; how, the pressure persisting, the beds in refusing further to fold have had, perforce, to snap, causing the set of beds on the upper side of the fissures so formed to slide upwards to where they came temporarily to rest some scores of feet above their counterparts."

VII. Relation of Auriferous Areas to Structure.

The subject of "favorable stratigraphical zones" from the point of view of the gold miner has been prominent since the early days of the gold-fields. Hall (6, pp. 76-77) discusses it, and after giving an account of the recognition of auriferous and non-auriferous bands, sums up:—"When we reach what Selwyn states to be the highest beds of the district . . . the quartz reefs are barren . . . In the Lancefield rocks again no gold occurs. It appears then that the auriferous strata of the Lower Silurian [i.e., Ordovician, Ed.] rocks begin above the base of the apparently thick *Tetragraptus fruticosus* zone, and range at any rate as high as *Phyllograptus,* but probably no higher." Selwyn's placing of the highest beds as along the Muckleford Creek has been confirmed, though the "more numerous reefs" referred to in a part of the above paragraph not quoted are possibly those of the Lancefieldian series west of Muckleford Creek. The range of *Phyllograptus* as understood by Hall would be up to the middle Castlemainian, while the "Lancefield rocks" would refer only to the original type locality north of the old Mount William Railway Station—a point overlooked by Junner (15, p. 211). It may be noted that we have found *Phyllograptus* at the type C2 locality in Victoria Gully, and that it is common in the Darriwilian.

E. J. Dunn, formerly Director of Geological Survey, also held the opinion that there were favorable and unfavorable beds, his "favorable beds" being the "Bendigo zone, especially the upper portion" (3, p. 170).

H. Herman(12) discusses Dunn's conclusions, and points out that at Bendigo beds on a particular horizon which are favorable in one mine or group of mines may be unfavorable in others, and the only generalization which seems to hold as to favorable beds in the district we have studied is that the Darriwilian series is invariably unfavorable, though the older series are not uniformly favorable. The question apart from this seems rather to be one of structure than of age, and will be discussed from a structural stand-point. Before we proceed to do this, attention may be called to Junner's similar discussion of a younger area(15), and also to the conclusions arrived at by Gepp, Baragwanath, and Stillwell, in a report on our present area(4). These conclusions are:—

(1) The Darriwil beds have so far been uniformly barren.
(2) The upper beds of the Castlemainian have contained productive fault reefs. Occasional saddle reefs are known, but productive spurry reefs are more characteristic.
(3) The Bendigo horizon has been proved to contain numerous productive saddle reefs in addition to productive spurry reefs.
(4) Saddle reefs occur in beds of the Lancefield horizon, but there is a tendency towards the occurrence of "indicator" gold.

These opinions, which may be taken as the most authoritative yet expressed on the subject, are quoted in full, as the present paper is based on the realization of "the importance of the extension and continuance of the detailed geological mapping in order to delimit the more productive horizons and to elicit the facts bearing upon the chance of success of further exploration and deep sinking"(4).

In considering the connexion between structure and auriferous areas, only reef mining is considered, except where the original source from which alluvial gold was shed can be indicated. A map on which auriferous areas are marked shows that they appear to be limited to several meridional belts. This depends on the more or less north-south strike, but a study of structure shows just what fields may be regarded as related. Structurally, Maldon is connected with Yandoit and Daylesford, while Castlemaine is linked up with Trentham and Blackwood. The Lauriston gold-field is on a structural line still further east. This line continued to the north includes Taradale, and would pass through Bendigo, but the great plutonic mass of Mount Alexander prevents reliable correlation between the belts on its north and south sides.

Another point, already referred to, is that the stratigraphical mapping shows that auriferous reefs in this district have been worked in the Lancefieldian, Bendigonian, and Castlemainian

series, but not in the Darriwilian. It does not follow, however, that gold is to be found in a region merely because its rocks are, for example, of Bendigonian age, but, on the other hand, the absence of gold-mining from the Darriwilian is clearly shown.

Interpreting this evidence structurally, it appears that the anticlinoria of the district are favorable for gold, synclinoria are unfavorable. This conclusion is empirical—the result of observation—but it can be defended on logical grounds. Thus, anticlines are notoriously lines of tensional stress, and the fractures caused by the stresses they have suffered would make them peculiarly favorable for the infiltration of mineral solutions. This is only an inadequate explanation, since quartz reefs are not limited to any one series, but occur in all. Our observations would also seem to indicate that the "nose" of an anticlinorium where the pitch steepens, or where reversal of pitch occurs, seems to have been favorable for the deposition of gold. These conditions seem to apply at Daylesford, Fryerstown, and Castlemaine, but in the light of observations made at Bendigo(12) on all such factors as stratigraphical age, folding, and pitch, the difficulty of making any generalizations will be realized.

Other results bearing on the deposition of gold have been the determination of the stratigraphical age of certain areas which hitherto had not been fixed. Thus Lauriston and Maldon both turn out to be Lancefieldian. This is of importance, as in the past stress has been placed on the recurrence of saddle reefs at Lauriston(13) though it is added that profitable mining had been mainly on an inverted saddle or synclinal reef. It is possible that the Lauriston gold-field may resemble Ballarat rather than Bendigo, and also that, though "indicators" do not seem to have been recorded in the district, they should be worth prospecting for.

VIII. Critical Localities and Suggestions for further Work.

In so extensive a district, where only comparatively small areas have been studied in detail, and then usually from a different point of view from that of the palaeontologist, it must happen that there are portions where further and more detailed search for fossils is desirable.

Commencing in the west, details are desirable in the country to the east of Campbelltown and west of Newstead. There is also a gap between Welshman's Reef and the Muckleford Creek, where further discoveries may be made. On the whole, however, the localities along the line of the Muckleford Creek seem decisive, though a critical examination of the line between Franklinford and the Castlemaine–Maryborough railway might yield important information.

Our information is fairly full for the Castlemaine sector(9), and it seems unlikely that more detailed work will modify our conception of the stratigraphy of this area except in details. The same remark applies to the area north-west of Glenlyon. Minor anticlines of Bendigonian beds may break the continuity of this Castlemainian synclinorium, but it is improbable that our general mapping here is in error.

East of Glenlyon, the case is different. Between Glenlyon and Lauriston the note on Q.S. 9 S.W. reads, "High scrubby ranges intersected with numerous deep gullies, probably auriferous. The prevailing rocks are coarse and fine-grained sandstones of different shades of grey and brown; micaceous shales occur only as occasional beds. Quartz reefs are abundant, having the same direction as the schist rocks with which they occur—N. 10-20° W." Certainly this is not encouraging country in which to search for graptolites, and our own efforts, necessarily limited, have been unsuccessful. Yet the provisional zoning of the stretch of country from Fryerstown and Taradale in the north to Glenlyon and Drummond in the south must be regarded as unsatisfactory, and subject to revision when further data shall have been collected.

The same remark applies to the belt shown as Lancefieldian east of Taradale. Here again fossils have not been found, except along the western margin.

It is hoped that the present paper will provide an outline which can be filled in by others, who, taking smaller areas for study, will be able to work them out in greater detail. One important point which such detailed work will make clear is the normal thickness of each zone to be expected in any part of the district. When this is known, we shall have a clearer idea of the structure of the whole area.

IX. List of Principal Graptolite Localities in the Area.

In the following list of principal graptolite localities it may be noted that:—

(i) In districts where a more or less complete succession has been worked out, as around Castlemaine, reference is given only to the records of previous workers.

(ii) Where no zonal reference is given, the serial age only has been determined or numerous beds of differing ages occur.

(iii) Except where otherwise stated, the determinations are those of the present writers.

(iv) Names in brackets indicate parishes, e.g., (Maldon).

I. Lancefieldian Series.

[Zones of *Dictyonema* and *Bryograptus* (L3); *Bryograptus* (L2), *Tetragraptus approximatus* (L1).]

A. Maldon, Dean Anticlinoria.

(*a*) Maldon area—

(i) Old mining dumps, east of Maldon–Castlemaine road, about 20 chains south of South German shaft (Maldon) (L2).

(ii) "Flying Pig" dumps, about 1 mile south of Maldon, on Maldon-Newstead road (Maldon) (L2).

(iii) Several outcrops in Tarrengower Creek, between Maldon and Welshman's Reef (Maldon) (L2 and 3).

(iv) Dumps on north of road to Goldsborough mine, west of (iii) (Maldon) (L2).

(v) Dumps near road junction north of (iv) (Maldon) (L2).

(vi) Cuttings on Maldon–Castlemaine railway, near Fentiman's Reef (Maldon) (L2).

(*b*) West of South Muckleford—

(i) Note 35 "Graptolites," Q.S. 15 N.E. (Strangways) (L1).

(*c*) Yandoit area—

(i) Allotment 19A of section XII. (Yandoit), 25 chains west of Yandoit State School (L3).

(ii) Road cutting south of Clydesdale, Newstead–Yandoit road (Yandoit) (L1). T. Smith coll.

(iii) Dumps of Golconda Mine, S.W. of Yandoit (Franklin). (Lancefieldian?—only record, *Clonograptus*.)

(*d*) Bullarook–Wombat–Dean area—

See T. S. Hall's identifications(7).

B. Trentham–Lyonville Anticlinorium. (References, except (iv.), to unpublished work of the late H. Foster, Geol. Surv. Vict.)

(i) Near the north-west corner of Township of Lyonville (Bullarto) (L3).

(ii) Near Newbury (Trentham) from old shaft near Old Snake Gully mine.

(iii) Trentham–Daylesford railway, about 1 mile west of Trentham (Trentham).

(iv) Kangaroo Creek (Coliban). Several bands of badly-cleaved decomposed black slate occur about 40 chains south of the Spring Hill–Glenlyon road. No graptolites were obtained *in situ* in these, but a piece of similar slate in the bed of the creek showed *Bryograptus* sp.

C. Taradale–Lauriston Anticlinorium.

(*a*) Taradale area—

(i) Road cutting north of railway crossing near Taradale Railway Station (Elphinstone) (probably L2).

(ii) Road cutting about 30 yards south-west of Taradale Railway Station (Elphinstone) (probably L2).

(iii) Old mining dump west of creek, in allotment 14, Township of Taradale (L2).

(iv) Road cutting at south-west corner of allotment 36 of section 10 (Elphinstone). The only graptolite found was *Clonograptus*.

(v) Old mining dumps opposite side of east and west road to allotment 9 of section 11 (Elphinstone) (L2).

(vi) Old mining dump near "65 miles" Q.S. 9 N.W. allotments 50-51 (Edgecombe) (L2).

(vii) Dumps of Ironstone Mine, south-east corner, allotment 55 (Edgecombe) L2-3).
(viii) Old mining dumps, Little Wonder Lead, N.W. of Malmsbury Railway Station (Edgecombe) (L3).

(*b*) Fryerstown–Taradale area—
We found no determinable graptolites between Taradale and Fryerstown until the higher beds near Fryerstown were reached. Fragments with primitive thecae were found near the Coliban-Loddon Divide, near Fryerstown–Taradale road.

(*c*) Lauriston area—
(i) Aroona shaft, allotment 59A (Burke) (L2).
(ii) Shaft in allotment 5 (Burke), west of (i) (probably L2).
(iii) Kangaroo Reef, Ba 77, Q.S. 9 S.W. (Burke) (L3).
(iv) Russell's Reef, Amalgamated, shaft in Lauriston Township (Lauriston) (only record, *Bryograptus*).
(v) Energetic Reef, allotment 286 (Lauriston) (L2).

(*d*) Tylden area—
(i) Allotment 3 (Tylden) (note on Q.S. 9 S.E.).
(ii) Premier Mine, allotment 82 (Tylden) (L3).
(iii) Coliban River, allotment 98 (Tylden).
(iv) Coliban River, north of allotment 96 (Tylden).
(The last two localities from H. Foster's records.)

II. Bendigonian Series.

(Zones of *Tetragraptus fruticosus* and *T. fruticosus* with *Didymograptus* cf. "*protobifidus*.")

A. Werona Synclinorium.

(*a*) Newstead–Campbelltown area—
(i) Numerous localities in the north-east of the Parish of Campbelltown. T. Smith.
(ii) Allotment 26 of section 12 (Tarrengower). (Locality on an old plan of W. H. Ferguson. We have been unable to verify it. Thin bands of black shale remind us of Lancefieldian.)

B. Dean Anticlinorium.

(*a*) Dean area—
See reference (7).

(*b*) Daylesford area—
See (7), (8), and (11).

C. Trentham–Chewton Anticlinorium.

(*a*) Chewton–Fryerstown area—
(i) West of Mt. Eureka (The Monk Hill) (Castlemaine) (B3-B1).
(ii) On both sides of Chewton–Fryerstown road, south of Specimen Hill (Chewton and Fryerstown).
(iii) South of Fryerstown (B4-B2).
[For further details see Harris (9).]

(*b*) Area south-west of Glenluce—
(i) Ba 80, Q.S. 15 N.E. (Fryerstown) (B1).
(ii) Along Glenluce–Glenlyon road (west of Loddon River) (Holcombe).
(iii) Sebastopol Diggings (Holcombe).

(*c*) Glenlyon area—
(i) Allotment 3 (Glenlyon), on Loddon River, above falls.
(ii) Quarry, allotment 7 of section 1 (Glenlyon) (H. Foster).

(*d*) Lyonville area—
(i) On boundary of Township of Lyonville.
(ii) Around Blackwood (Blackwood) (south of mapped area).

D. Area between Lauriston and Trentham Anticlinoria.

The only records are from the extreme north and south.

(*a*) North—

At both east and west approaches to Elphinstone railway cutting (Chewton and Elphinstone).

(*b*) South—

On Coliban River, in north-west corner of Parish of Trentham.

E. Eastern area.

Our only record is of B3 from Italian Diggings, below Mitchell's Falls, Campaspe River, Q.S. 13 S.E.

III. Castlemainian Series.

(Zones of *Isograptus caduceus* var. *primula* and *lunata* to *I. caduceus* var. *maxima-divergens.*)

A. Werona Synclinorium.

(i) South bank of Deep Creek, Werona (Campbelltown) (C5), coll. T. Smith.

B. Around Dean Anticlinorium.

See references (7, 8).

C. Muckleford Synclinorium.

(i) Castlemaine area. See Hall (6) and Harris (9).

(ii) Between allotment 8 of section IX. and 13 of VIII. (Yandoit) (C1).

(iii) In south-east corner of section IV.A (Yandoit) "Rocky Waterholes Creek" Q.S. 15 S.E. (C1).

(iv) South of Vaughan (Fryerstown) (C5).

(v) Sebastopol Diggings (Holcombe) (C5).

(vi) North of Glenlyon Township (C4). See note in extreme south-west corner of Q.S. 9 S.W.

(vii) For numerous records in the Bullarto district we have depended on the work of H. Foster.

D. Expedition Pass Synclinorium.

(i) On both sides of Forest Creek, north of Chewton (Faraday and Chewton) (C3-C1).

(ii) South of the Chewton–Elphinstone railway (C5-C1). See also Harris (9).

(iii) North-east of Parish of Fryerstown (C3 and higher).

E. South-eastern area.

Numerous Castlemainian localities along the Campaspe River, south-west of Woodend (C5-C1) (H. Foster and the authors).

IV. Darriwilian Series.

(Zones of *Oncagraptus, Cardiograptus, Glyptog. austrodentatus,* and zones with *D. nodosus,* &c.)

A. Muckleford Synclinorium.

(i) Northern area. See Harris, cit. sup.

(ii) Between sections II. and VII. (Yandoit)—several localities.

(iii) Allotment 11 of section II. (Yandoit) (D4), coll. T. Smith.

(iv) Between allotments 4 and 5 of section IV.A (Yandoit).

B. Bullarto Synclinorium.

D5 recorded by H. Foster, on Leitch's Creek, about ½ mile upstream from mineral spring on road from Musk.

C. Expedition Pass Synclinorium.

(i) On both east and west of bridge over Chewton–Elphinstone railway at 73½ miles (D5).

D. South-eastern area.

(i) Numerous localities on both sides of the Carlsruhe–Lancefield road, and between this road and the Mt. Macedon igneous series (D1).

(ii) On main Bendigo road, about ½ mile north of Clock Tower, Woodend (Woodend) (D1).

(iii) Between allotments 95 and 98, north-east of Woodend (Woodend) (D1).

(iv) Ba 74 Q.S. 10 N.E., south-west of "Woodend Town Common" (D2).

(v) South of the mapped area, extending south from Woodend to beyond Gisborne, there is an extensive belt of Darriwilian beds, with probably a complete series along the Gisborne Creek.

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